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Geophysical Research Abstracts,
Vol. 10, EGU2008-A-10690, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-10690
EGU General Assembly 2008

Integration of terrestrial laser scanning and the Permanent Scatterers technique for instability analyses in urban areas.

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Displacement monitoring and analysis in urban areas is one of the most important topics for landslide risk mitigation.

Mdina (also known as “Città Notabile” and the "Silent City") is situated in the centre of the island and was the ancient medieval capital of Malta. It has narrow, cobbled streets and from its hilltop position it commands a magnificent view of the Island.

The geological setting of the town consists of a stiff, brittle plate belonging to the Upper Coralline Limestone Formation overlying clays from the Blue Clay Formation. The mechanical characteristics of the materials comprising the rock slab – soft substratum system are very different in terms of strength, stiffness and brittleness and these contrasting properties are the main cause of the serious damage to portions of the town bastions and structures.

A combination of terrestrial laser scanning and Permanent Scatterers (PS) techniques are being used to identify and characterize the most critical areas and the causes of the displacements. The laser scanning instrument is a long range 3D laser scanner (RIEGL LMSZ410-i) which is capable of determining the position of up to 12000 points/s with a maximum angular resolution of 0.008˚ and an accuracy of $\pm$ 10mm from a maximum distance of 800m.

In particular, the laser scanner survey of the study areas was performed with the aim of constructing a 3D digital model of both the structures and the slopes of the intervention

areas. This will allow the construction of a 3D map of the main cracks affecting the structures, with the aim of identifying the structural deformation pattern for facilitating the correct interpretation of the PS satellite data.

To completely cover the selected study areas, a total of 56 surveys from different scan positions were performed. The different point clouds were then linked to a project reference system with the aid of reference points, the coordinates of which were accurately defined by differential GPS.

Detailed geologic, geomorphologic and geomechanical surveys were also performed, to correlate local stratigraphy and soil - rock mass geotechnical characteristics with overlying structures, damaged areas and instability phenomena.

Finally the PS InSAR monitoring technique was employed to understand the historic movements of the structures and to monitor current displacements. In the case of slow movements (up to a few cm/year) in built-up areas, multi-interferogram approaches such as the PS technique, are able to retrieve the spatial distribution of displacements and their evolution within the monitored period with millimetric precision. Thanks to the availability of radar satellite images starting from 1992, the technique can be applied to provide the differed-time analysis of past movements and to observe present-day displacements. The technique provides displacement measurements along the satellite line of sight which can be used for phenomena characterized by prevalently vertical movements. As PS were extracted over the entire town of Mdina, this technique will also provide useful information for determining the actual dimension of the areas requiring intervention.

Based on the results of these analyses, a monitoring programme will be set up for the most sensitive areas, and consequent remedial works will be determined.